Synthesis of effects of dissolved copper on juvenile salmonid olfaction using a benchmark concentration analysis

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Abstract

Dissolved copper (dCu) is a ubiquitous, toxic pollutant in U.S. surface waters. As such, copper is one of 126 priority pollutants listed pursuant to the U.S. Clean Water Act. Recent experimental results confirm marked toxicity to multiple fish endpoints including fish sensory systems and behaviors. Since sensory system mediated behaviors are important to the survival, reproduction, and distribution of anadromous salmonids (many of which are listed as threatened or endangered pursuant the U.S. Endangered Species Act of 1973), it is important to characterize dCu exposure concentrations that may result in adverse responses. Specifically, dCu impaired the ability of juvenile salmonids to smell and by extension reduced their capacity to detect and respond to alarm signals (conspecific skin extracts). In this poster, a benchmark concentration analysis is conducted on a recent dose-response dataset with juvenile coho exposed to dCu (e.g. 2, 5, 10, and 20 µg/l). Olfaction and behavioral impairment endpoints were significantly correlated ($r^2 = 0.94$) and indicated statistically significant effects (alpha =0.05) at all concentrations tested for olfaction (2, 5, 10, 20) and at 5, 10, and 20 µg/L for alarm response (inhibition of swimming speed reductions). No experimental treatments were tested below 2 µg/L (corresponding to ~ 50% reduction in EOG and alarm response), therefore significant uncertainty arises as to what concentrations between 0 and 2 µg/L dCu affect juvenile salmonids olfactory capacity. Benchmark concentrations for dissolved copper's effect on juvenile salmonids are presented in Table 2. They ranged from **0.18 - 2.10 ug/L** These results indicate juvenile salmonid sensory systems are particularly sensitive to dissolved copper at low µg/L concentrations.

Introduction

•The U. S. Endangered Species Act of 1973 requires assessing the potential effects of "actions" by federal agencies on Threatened or Endangered Species

• "Actions" with copper may include re-registration of copper containing pesticides, establishment of water quality criteria and state water quality standards, discharges originating from point and non-point sources including impervious surfaces and alteration of land use through residential, commercial, and transportation development

• Copper affects sublethal, lethal, and chronic biological endpoints (Table 1).

•Copper is a potent neurotoxin that directly damages the sensory capabilities of salmonids (e.g. olfaction) at low concentrations (ppb).

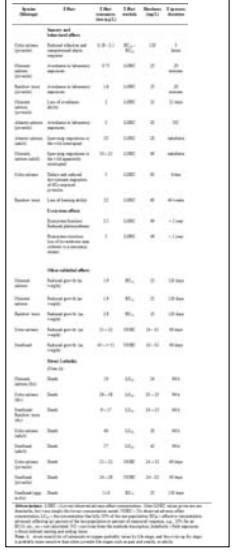
• Effects can manifest within 30 minutes and can persist for weeks.

• Multiple studies suggest that anthropogenic inputs of dissolved copper to salmon habitats are at levels that likely impair sensory systems and by extension important behaviors involved in predator avoidance, homing, growth, migration, and reproduction; each is important to the continual survival of individuals and recovery of at risk populations.

•A key data gap is, what concentrations adversely affect individual threatened or endangered juvenile salmonids.

• Here we conducted a benchmark concentration analysis to present examples that represent the dissolved copper concentration (above background) expected to reduce juvenile salmonids' ability to detect and avoid predators in fresh water.

Table 1. Dissolved copper may cause a range of adverse acute, chronic, and sublethal effects in fish as well as in aquatic invertebrates and algae.



Objectives

1. **Conduct a benchmark concentration analysis**
2. **Present examples of dissolved copper effect thresholds**
3. **Discuss potential implications to threatened or endangered salmonids**

Materials and Methods

Benchmark Concentration Analysis

•Benchmark concentrations (BMC) were calculated using an EPA methodology to provide examples of effect thresholds in juvenile salmonids (USEPA 1998)

•A sigmoidal logistic model was applied top a dose-response dataset depicting copper's affect on salmonid olfaction olfaction (depicted in Figure 1)

•Sigmoid Logistic Model:

$Y = m/[1+(x/k)^n]$

Where

m = Maximum EOG amplitude

y = EOG amplitude

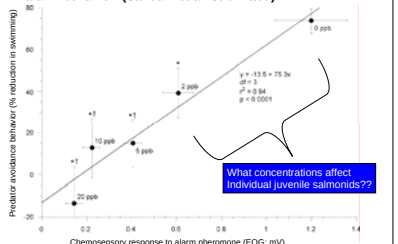
x = dissolved copper concentration

k = copper concentration at half-maximum EOG amplitude (EC50)

n = slope

Dataset used to conduct Benchmark Concentration Analysis

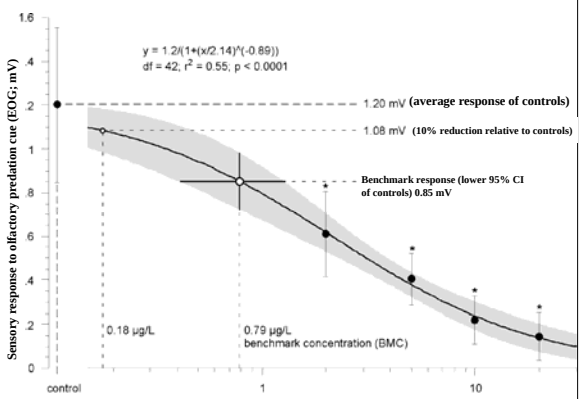
Figure 1. Copper-induced reductions in juvenile salmonid olfactory physiology and behavior are significantly correlated. Fish exposed to dissolved copper (3 h) showed reduced olfactory sensitivity and a corresponding reduced alarm behavior. (Sandahl et al. submitted)



Points represent treatment means (with copper exposure labeled to the right); error bars represent one standard error; n=8-12 individual coho salmon; * represents a statistically significant difference in olfactory response (EOG data) compared to controls (one-way ANOVA with Dunnett post hoc test, p<0.05); †represents statistically significant difference in alarm response to skin extract (% reduction in swimming) compared to controls (one-way ANOVA with Dunnett post hoc test, p <0.05). The line represents a statistically significant linear regression based on treatment means (n = 5; p < 0.0001; r2 = 0.94). 1 ppb = 1 µg/l.

Results and discussion

Figure 2. Example of a benchmark concentration for copper's effect on juvenile salmonid olfaction.



Filled circles represent treatment means; error bars represent the 95% confidence interval of the mean; n=8-12 individual coho salmon; * represents a statistically significant difference in olfactory response (EOG data) compared to controls (one-way ANOVA with Dunnett post hoc test, p<0.05). The line represents a statistically significant non-linear regression based on individual fish (n = 44; p < 0.0001; r2 = 0.55). The gray band represents the 95% confidence band for the non-linear regression line. The non-linear regression used a standard sigmoid function with the maximum constrained to the control mean (1.2 mV; indicated by the upper horizontal dashed line). Therefore, the control fish were not included in the non-linear regression. The lower bound of the 95% confidence interval of the control mean (0.85 mV) is indicated by the lower horizontal dashed line and represents an example of a benchmark response (BMR). The open circle denotes where the regression line crosses the BMR and denotes the corresponding benchmark concentration (BMC). Horizontal and vertical lines through the open circle highlight the 95% confidence intervals for the BMC based on the results of the non-linear regression.

Results and Discussion

Table 2. Benchmark responses and associated concentrations for juvenile salmon exposed to dissolved copper for 3 hr. Response values are for a loss of olfactory function or a reduction in the sensory response to a chemical predation cue as measured via EOG recordings. Behavioral impairment indicates a predicted decrease in predator recognition and avoidance, as indicated by reduced alarm response

Benchmark Concentrations[1]		Benchmark Responses[2]		Behavioral Responses (predicted)[3]
Value[4] (µg/l)	95% CI[5] (µg/l)	Departure from mean of controls		Departure from mean of controls
		Statistical[6] (CI of control mean)	Relative[7] (% reduction in olfactory response)	Relative[8] (% reduction in alarm response)
0.18	0.06 - 0.52	NA	10.0	8.3
0.59	0.30 - 1.16	Lower 90%	24.2	25.6
0.79	0.44 - 1.42	Lower 95%	29.2	31.8
2.10	1.60 - 2.90	NA	50.0	57.2

1 the dose (concentration) producing a predetermined, altered response for an effect (EPA/630/R-94/007; 02/1995)
2 the predetermined level of altered response or risk at which the benchmark dose (concentration) is calculated (EPA/630/R-94/007; 02/1995)
3 based on the linear regression shown in Figure 2
4 corresponding concentration, see Figure 3 and text for calculation method
5 confidence interval for the value based on the non-linear regression
6 location of the value with respect to a confidence interval of the mean of the controls
7 amount of reduction represented by the value relative to the mean of the controls
8 amount of reduction represented by the value relative to the mean of the controls

• Benchmark concentrations for dissolved copper's effect on juvenile salmonids are presented in Table 2. They ranged from **0.18 - 2.10 ug/L**

• Benchmark concentrations corresponded to reductions in alarm response of **8.3 - 57.2%.**

• These BMCs are within or slightly less than other effect concentrations (Table 1).

• Interestingly, the estimated acute Criterion Maximum Concentration (CMC) based on the Biotic Ligand Model (using measured and estimated water quality parameters in Sandahl et al. submitted) ranged from **0.6 - 3.2 ug/L** while the EPA based hardness based acute CMC was **6.7 ug/L**.

Conclusions

• The benchmark concentration method predicted that dissolved copper concentrations of <1 ug/L (3 h exposure) can significantly reduce juvenile salmonid's ability to detect and respond to a predation event (Figure 2; Table 2).

• Concentrations of dissolved copper in stormwater from nonpoint sources and estimated concentrations from pesticide applications frequently exceed these benchmark concentrations, at times by more than 3 orders of magnitude, 5-735 ug/L; median = 35 (Hahn et al. 2006).

•Since reductions in alarm response increases the probability of being eaten by predators (birds and fish), it is important to address this risk to individuals in Endangered Species Act Consultations involving dissolved copper.

•A key requirement to address this risk is to estimate or measure dissolved copper concentrations in effluent and receiving surface waters.

•Given these thresholds and monitoring data, impairment of juvenile salmonid olfactory capabilities and mediated behaviors is potentially occurring throughout the freshwater range of threatened and endangered salmonid populations.

Data Gaps

• Site specific water chemistry parameters (DOC, Hardness, alkalinity, pH, etc) influence the bioavailability of copper to fish gills, however it remains uncertain how these parameters affect fish sensory neurons and specifically the olfactory response (please see J. McIntyre presentation Thursday PM).

•Equally uncertain is the effect of dissolved copper on sensory system responses in salt water.

• The effect of dissolved copper on other behaviors mediated by olfaction such as those involved in migratory and reproductive success, and juvenile growth remain largely unknown.

Acknowledgement

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References

Han YH, Lau SL, Kayhanian M, Stenstrom MK. 2006. Correlation analysis among highway stormwater pollutants and characteristics. Water Science and Technology, 53:235-243.
Sandahl JF, Baldwin DH, Jenkins JJ, Scholz NL. Submitted. A sensory system at the interface between urban stormwater runoff and salmon survival. Submitted to Environmental Science and Technology.